ROYAL AEROSPACE ESTABLISHMENT

PERCEIVED URGENCY OF WARNING SIGNALS DETERMINED USING A FORCED CHOICE PAIR COMPARISON TECHNIQUE

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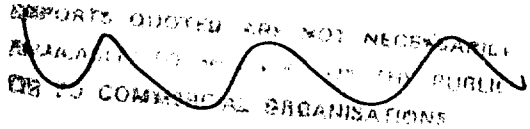

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SUMMARY

Following work by RAE (Farnborough), ISVR (Southampton University) and APU (MRC, Cambridge) a set of 40 high urgency warning signals were designed for RAE. The spectral content of the signals was designed to compensate for the acoustic characteristics of the aircraft, flight helmet and communication system.

An experiment was designed to select, from these 40 signals, the six which were perceived as conveying the greatest urgency, and then, to assess these in a set including four previously selected signals already in use in experimental auditory warning signals.

The data confirmed that those signals intended to be of the highest urgency were ranked correctly and that the relationships, in terms of perceived urgency, amongst the complete set of ten signals was as predicted.

A self-paced learning experiment was performed which showed that the signals were easily learnt and that there was no significant confusion amongst them.

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LIST OF CONTENTS

1 INTRODUCTION

Audible warnings form an important means of indicating alarms or system malfunctions to a pilot. Where a number of audible warnings are used it is important that they be designed as a set, rather than be assembled piecemeal.

Earlier work[1-5] showed that warning signals could be designed such that the urgency of the warning is conveyed by the detail of each signal. Thus, highly urgent signals could be presented without recourse to the use of high output levels causing adverse effect such as 'startle'.

In order to meet the need for signals of higher priority for 'Immediate Action' alerts, RAE discussed with APU (designers of the original set), a range of signals each with a higher priority than any of the signals previously supplied. As a starting point RAE supplied APU with signals, in current use, known to convey extreme urgency.

From these APU were able to construct 20 examples of such signals each in two formats - one format conveying higher urgency than the other, but both having essentially the same temporal and spectral construction. The signals designed to be of lower urgency were designated as 'Initial' signals, and those intended to be more urgent as 'Urgent' signals.

Three of these signals were required for potential installation, in the RAE Lynx and Sea King and the RAF Puma and Chinook, along with four signals from the set examined in earlier work. Before installation of these signals in the appropriate aircraft it was necessary to confirm that the new signals bore the correct relationship, in terms of perceived urgency, to existing signals, and that the set of signals finally chosen would not contain any which could be confused with any others in the set.

The following requirements were to be met:

(i) The three 'Immediate Action' signals should be those that conveyed the highest sense of urgency out of the 40 new signals;

(ii) The three 'Immediate Action' signals should be demonstrated to be more urgent than the 'Immediate Awareness' and 'Awareness' signals examined earlier. Also, the latter pair should be shown to be ranked correctly in terms of urgency;

(iii) The seven signals finally selected should be shown to present no difficulties in terms of learning or confusion amongst the seven.

2 EQUIPMENT

All the experiments described here were conducted in the MM4 Noise and Vibration Simulator[6].

2.1 Urgency experiments

All instrumentation was exactly as described in earlier work[3,4], with the exception that the format of the keypad used by subjects to record their responses was changed. Only two keys of the keypad were used and these were labelled 'A' and 'B'.

Software was written to control the urgency experiments and to analyse the data. Programs were written in Fortran 77 to run under RSX 11M+ on the PDP 11/84 which was attached to an FPS-100 array processor and a BBC microprocessor.

2.2 Confusion experiment

Both hardware and software for this experiment were identical with that described in earlier work[3,4].

2.3 Signals

2.3.1 Urgency

The two sets of 20 signals formed the set to be assessed during the first three urgency experiments. Although these formed 20 pairs of 'Initial' and 'Urgent' signals and although the main interest was in the most urgent sounding signals, all 40 signals were assessed during the first two experiments. The most urgent ten from each of these experiments were then grouped together in a third trial. The most urgent six of these were then joined with four other signals in a fourth trial.

The new signals were arbitrarily numbered 1 to 40 with 1 and 21, 2 and 22, and so on, being the 'Initial' and 'Urgent' versions respectively. Tables 1 to 4 show which signals were used in each of the urgency experiments. In Table 4 the most urgent six from the first three trials are joined with four other signals. Two of these, designated as 'Immediate Awareness' and 'Awareness', are signals dealt with in earlier work[3,4].

The remaining two are signals formulated at RAE, and were introduced in order to provide a comparison between the new warnings and established warnings, such as the 'Lyrebird'. The first of these is a simple swept square wave (600 Hz to 1700 Hz, in 1 second, with a duty cycle of 75%, repeated twice), known as a 'Lyrebird' warning signal, and the second is a derivative of this where the rise

time of the signal conforms to the APU generated signals (to avoid 'startle' effects) where additional swept square waves (with inharmonic relationships to each other) have been added to the original 'Lyrebird'.

2.3.2 Confusion

Table 5 lists the signals used in the confusion experiments. The most urgent sounding six signals from the work above were joined with four other signals. Two of these had been assessed previously in the fourth urgency experiment. These were the 'Immediate Awareness' and 'Awareness' signals, which were ranked correctly with the 'Immediate Action' signals and with each other.

The remaining two were also signals used in earlier work[3,4]. These are the signals labelled 'Information' and 'Low Height', which are both of a different character to other signals and were not included in any urgency experiments for this reason.

3 PROCEDURE

3.1 Urgency

During this work, experienced subjects performed four complete, paired-comparison rank-ordering experiments. When seated in the simulator, subjects were asked to choose which of two, consecutively presented, warning signals sounded the more urgent. The order of presentation of the pairs of signals was random and the order of presentation of the signals within each pair was balanced.

Signals were presented through earphones and identified on a VDU screen as 'A' or 'B'. A button panel allowed the subjects to record the choice made. All activities were computer controlled and the experiments were self-paced in that the system waited for a response after each pair before proceeding to the next.

Each subjects performed $n(n-1)$ judgements where n equalled 20 or 10. In the case of $n = 20$ the number of judgements was considered to be too large for subjects to maintain concentration over the whole period. Accordingly, the software was designed to split such experiments into four separate occasions, resuming the presentations at the appropriate point on each occasion.

Additional software packages were written to analyse the data. Rankings for each set of signals were produced for individual subjects and over all subjects.

3.2 Confusion

The procedure used in this experiments was identical to that described in earlier work[3,4].

4 RESULTS

4.1 Urgency

The rankings produced by the experiments are shown in Tables 1 to 4 for trials A, B, C and D. The signals used in trial C were the highest scoring ten signals from each of trials A and B. Six signals from these were used in trial D and in the confusion experiments. The six chosen were those that were ranked highest in trial C.

Four of these (or their 'Initial' versions) were in the highest scoring six in both trials A and B. The remaining two, signals 33 and 34, had scored well in trials A and B.

In trial D the six 'Immediate Action' signals were combined with 'Immediate Awareness' and'Awareness' signals (labelled 'Fire' and 'Electrics' in earlier work[3,4]) and with a standard 'Lyrebird' and a modified 'Lyrebird' (both constructed at RAE).

The results from trial D show that the 'Immediate Awareness' and 'Awareness' signals are ranked correctly, both with respect to the 'Immediate Action' signals and with respect to each other. The scores achieved by the highest scoring of the 'Immediate Action' signals compare favourably with the score of the 'Lyrebird' signal, which is commonly used as an urgent warning in aircraft cockpits.

The results from trial C are of interest in that, not only do they show that the signals are internally consistent, that is, the 'Urgent' versions of a particular signal are always ranked higher than the corresponding 'Initial' version, but also, that with three exceptions, all 'Urgent' signals are ranked higher than all 'Initial' signals. The three exceptions to the latter are that the 'Initial' versions of signals 10, 12 and 20 rank higher than 'Urgent' versions of other signals. These points show support for the design methods of APU.

4.2 Confusion

The signals used in urgency trial D were installed in the software used for the confusion experiments[3,4]. The 'Lyrebird' and 'Modified Lyrebird' were

replaced by two signals from the earlier experiments (labelled 'Information' and 'Low height'[3,4]).

The results of the confusion experiments are summarised in Table 6. There is very little evidence of confusion amongst these signals. Even in the data labelled 'section 1', where subjects were learning the signals for the first time, there is only one significant confusion and errors are generally few. In the section 3 data there are no significant errors at all and only 22 errors in total in 641 presentations.

The mean errors and completion times, per stage, of sections 1 and 3 are shown in Figs 1 and 2, with standard deviations. The scores produced by subjects during test sections 2 and 4 are shown in Fig 3.

These data all show similar behaviour to that reported in other work[3,4]. As before there is a marked change in the error rate and in completion times at the sixth and seventh stages, possibly due to a change in strategy adopted by subjects. This is shown very clearly in the section 3 data where the data values rise sharply at the seventh stage, but drop back to a continuation of previous trends for succeeding stages.

In general, these data values are lower for the later stages, eight, nine and ten, than those observed during earlier work, possibly indicating that this set of signals presented fewer problems during the learning process.

5 CONCLUSIONS

A balanced pair forced choice procedure was used to determine the most urgent sounding six signals out of two sets of 20 signals. These six were included with four more signals in a further forced choice experiment which verified that these signals bore the desired relationships, in terms of urgency, to each other.

Eight of these last set of ten were included, with two other signals, in a self-paced learning programme. The data from this experiment showed that there was a very low risk of confusion arising amongst these signals and that the signals were more easily learnt than other sets of signals examined earlier.

Subsets of these signals (see Table 7) have been installed in RAE and RAF helicopters for flight trials and one subset has been assembled for EH101 trials.

Acknowledgments

The authors wish to gratefully acknowledge the assistance of Ms S. James in the compilation of Table 7.

Table 1 - SIGNALS IN TRIAL A RANKED IN ORDER OF URGENCY

Ranked signals in first set of 20 (over 6 SS)

Score CL	Signal	Score GR	Signal	Score RW	Signal	Score DH	Signal	Score SL	Signal	Score JB	Signal	Score All	Signal
94.7	20	97.3	10	81.5	20	100.0	12	89.4	12	97.3	12	91.2	12
86.8	12	92.1	12	81.5	12	92.1	5	84.2	10	86.8	14	81.5	10
86.8	10	89.4	20	73.6	14	76.3	13	78.9	9	86.8	5	72.8	20
73.6	18	76.3	13	73.6	10	76.3	4	71.0	7	73.6	10	67.9	4
71.0	19	71.0	4	71.0	4	73.6	10	71.0	6	68.4	20	67.1	5
68.4	8	68.4	17	65.7	19	68.4	20	68.4	14	65.7	13	62.2	14
65.7	4	65.7	5	63.1	8	68.4	17	60.5	4	63.1	4	60.5	19
60.5	5	63.1	8	63.1	5	63.1	19	57.8	11	57.8	19	59.2	17
57.8	17	57.8	19	60.5	18	57.8	14	52.6	17	52.6	7	57.4	13
52.6	7	55.2	11	57.8	17	55.2	11	52.6	15	50.0	18	57.0	7
50.0	14	55.2	7	57.8	7	52.6	7	52.6	2	50.0	17	50.4	8
39.4	15	47.3	18	50.0	13	50.0	2	47.3	19	47.3	11	50.0	18
39.4	13	42.1	9	44.7	9	36.8	18	42.1	8	44.7	9	47.8	11
39.4	11	36.8	14	39.4	15	34.2	9	36.8	13	39.4	8	47.3	9
39.4	9	26.3	15	36.8	16	28.9	6	34.2	20	34.2	15	35.9	15
28.9	16	23.6	6	31.5	11	26.3	8	34.2	5	31.5	2	31.5	2
23.6	2	15.7	2	18.4	6	23.6	15	31.5	18	21.0	6	29.8	6
15.7	6	10.5	1	15.7	2	7.8	16	18.4	1	13.1	16	16.6	16
5.2	3	2.6	16	10.5	3	7.8	1	10.5	16	10.5	3	7.4	1
0.0	1	2.6	3	2.6	1	0.0	3	5.2	3	5.2	1	5.7	3

Table 2 - SIGNALS IN TRIAL B RANKED IN ORDER OF URGENCY

Ranked signals in SECOND set of 20 (over 6 SS) (21-40)

Score SL	Signal	Score CL	Signal	Score RW	Signal	Score DH	Signal	Score GR	Signal	Score JB	Signal	Score All	Signal
92.1	33	89.4	33	86.8	30	100.0	25	100.0	30	86.8	34	85.9	30
92.1	30	86.8	40	78.9	40	86.8	33	92.1	32	84.2	25	78.5	33
78.9	27	86.8	39	76.3	39	84.2	32	81.5	39	81.5	30	76.7	39
71.0	29	81.5	35	76.3	34	78.9	39	81.5	37	78.9	32	75.8	32
65.7	31	78.9	30	73.6	32	78.9	35	76.3	40	73.6	39	72.3	25
63.1	39	76.3	37	71.0	33	76.3	30	76.3	24	71.0	40	71.9	40
63.1	37	63.1	32	71.0	25	71.0	40	68.4	33	63.1	33	64.9	37
63.1	32	63.1	25	68.4	35	65.7	24	68.4	25	63.1	31	59.6	35
57.8	35	57.8	34	63.1	24	60.5	37	57.8	27	57.8	24	59.6	24
50.0	26	55.2	38	57.8	37	52.6	34	52.6	28	50.0	37	56.1	34
47.3	40	47.3	27	55.2	38	47.3	22	50.0	31	47.3	28	50.8	31
47.3	25	47.3	24	47.3	28	44.7	31	39.4	29	47.3	27	50.8	17
47.3	24	44.7	31	36.8	31	36.8	27	36.8	34	39.4	26	39.4	28
44.7	22	28.9	28	36.8	27	31.5	26	34.2	35	36.8	35	37.2	38
34.2	28	26.3	29	28.9	29	26.3	38	31.5	38	34.2	22	33.7	29
26.3	38	26.3	26	18.4	26	26.3	28	18.4	26	28.9	38	30.7	26
26.3	34	23.6	22	15.7	36	15.7	29	18.4	22	21.0	29	30.2	22
13.1	36	7.8	21	15.7	21	10.5	21	10.5	21	21.0	21	12.7	21
10.5	21	5.2	36	13.1	22	2.6	36	5.2	23	10.5	23	6.5	36
5.2	23	2.6	23	7.8	23	2.6	23	0.0	36	2.6	36	5.7	23

Table 3 - SIGNALS IN TRIAL C RANKED IN ORDER OF URGENCY

Ranked signals in third set of 20 (over 2 SS)

Score RW	Signal	Score JB		Score All	Signal
92.1	40	94.7	30	82.8	30
76.3	33	89.4	35	80.2	40
73.6	20	76.3	12	76.3	25
73.6	10	73.6	32	67.1	33
71.0	30	68.4	40	63.1	34
68.4	34	68.4	5	59.2	32
63.1	25	57.8	39	59.2	10
57.8	39	57.8	34	57.8	39
55.2	35	57.8	33	57.8	12
52.6	37	44.7	37	52.6	20
44.7	32	44.7	10	48.6	37
42.1	19	42.1	19	48.6	5
39.4	24	42.1	13	42.1	19
39.4	12	34.2	14	38.1	35
36.8	14	31.5	20	35.5	14
31.5	7	28.9	24	34.2	24
28.9	5	23.6	7	27.6	7
23.6	17	23.6	4	25.0	13
21.0	4	21.0	35	22.3	4
7.8	13	18.4	17	21.0	17

The signals chosen for the fourth trial were those ranked 1 - 6 in this trial. This trial was curtailed, mainly because the top six signals above corresponded to the signals which were in the top six in Trials A and B. As the signals in B were the urgent versions of the signals examined in A these were chosen for D.

Table 4 - SIGNALS IN TRIAL D RANKED IN ORDER OF URGENCY

Ranked signals in FOURTH set (of 10 over 5 SS)

Score RW	Signal	Score DH	Signal	Score TW	Signal	Score JB	Signal	Score KH	Signal	Score All	Signal
100.0	MLB	94.4	33	88.8	MLB	94.4	30	94.4	LB	81.1	MLB
88.8	40	77.7	MLB	88.8	33	88.8	A	88.8	MLB	65.5	30
77.7	LB	77.7	25	77.7	LB	66.6	32	77.7	30	63.3	33
61.1	30	61.1	32	66.6	40	50.0	MLB	61.1	33	60.0	LB
44.4	33	61.1	40	55.5	34	50.0	34	55.5	25	57.7	40
44.4	32	50.0	34	55.5	30	38.8	40	50.0	32	48.8	32
33.3	34	38.8	30	27.7	25	33.3	25	33.3	40	45.5	25
33.3	25	27.7	LB	22.2	32	27.7	IA	22.2	IA	41.1	34
16.6	IA	11.1	IA	16.6	IA	27.7	33	16.6	34	18.8	IA
0.0	A	0.0	A	0.0	A	22.2	LB	0.0	A	17.7	A

The ten signals were the highest scoring six (from Trial C) of the original forty from APU (all Urgent versions) together with the 'Immediate Awareness', 'Awareness', Lyre and Modified Lyre to set the results in some context.

Table 5

TEN SIGNALS USED IN CONFUSION EXPERIMENTS

Signal	Label	Warning type
30	THREAT	'Immediate Action'
40	UNDER-CARRIAGE	'Immediate Action'
25	FUEL	'Immediate Action'
33	SERVO	'Immediate Action'
34	ROTOR	'Immediate Action'
32	GEARBOX	'Immediate Action'

The six signals above are the most urgent six from the set of 40 used in the first two urgency experiments.

The four signals below are those found to be the most suitable, for the Warning type required, of the signals examined in earlier work[3,4].

FIRE	'Immediate Awareness'
ELECTRICS	'Awareness'
INFORMATION	'Information'
LOW HEIGHT	'Height Alert'

Table 6

CONFIDENCE TABLES FOR SECTIONS 1 AND 3 (SIGNIFICANT ENTRIES UNDERLINED)

Responses for Section 1

SIGNAL PRESENTATION	1	2	3	4	5	6	7	8	9	10	TOTAL
1 FIRE	90	0	2	1	1	0	1	0	0	0	95
2 ELECTRICS	4	89	0	1	0	0	4	0	0	0	98
3 INFORMATION	2	1	94	3	0	0	0	0	0	0	100
4 LOW HEIGHT	0	1	0	91	1	0	3	1	0	0	97
5 THREAT	0	1	0	0	87	2	1	2	3	2	98
6 UNDER CARRIAGE	0	0	0	0	0	97	1	1	0	3	102
7 FUEL	2	2	1	0	4	2	78	1	7	5	102
8 SERVO	2	2	0	1	4	1	3	78	3	2	96
9 ROTOR	0	0	0	1	1	4	4	0	85	7	102
10 GEARBOX	2	1	1	0	5	3	1	2	5	88	108
	102	97	98	98	103	109	96	85	103	107	

Responses for Section 3

SIGNAL PRESENTATION	1	2	3	4	5	6	7	8	9	10	TOTAL
1 FIRE	60	1	0	0	0	0	1	0	1	0	63
2 ELECTRICS	1	66	0	0	0	0	0	0	0	0	67
3 INFORMATION	0	2	56	0	0	0	0	0	0	0	58
4 LOW HEIGHT	0	0	0	66	0	0	0	0	0	0	66
5 THREAT	0	0	0	0	58	0	0	1	0	0	59
6 UNDER CARRIAGE	0	0	0	0	0	67	0	0	1	0	68
7 FUEL	0	0	0	0	0	0	64	0	2	2	68
8 SERVO	0	0	0	0	0	0	0	62	0	0	62
9 ROTOR	0	0	0	0	0	1	1	0	57	2	61
10 GEARBOX	0	0	0	0	1	0	4	0	1	63	69
	61	69	56	66	59	68	70	63	62	67	

Table 7

SIGNAL DESTINATIONS

Aircraft	Priority	A/c label	RAE label	Filename (S09)	Comment
PUMA-RAF	IAw	see comment	Fire	SI:[3,11]P2FIREATT.DAT	A range of voice messages were provided for immediate Awarness warnings for both PUMA and CHINOOK :- ENGINE 1; ENGINE 2; NO TRACK; RISING GROUND; DASH DASH; 'FIRE WARNING 1; FIRE WARNING 2
PUMA-RAF	Aw	MASTER CAUTION	Master Caution 1	SI:[3,11]WS16AIPMR.DAT	
PUMA-RAF	I	IFF CHANGE	Information	SI:[3,11]INFORAIMS.DAT	
PUMA-RAF	LH	LOW HEIGHT	Low height 2	SI:[3,11]M1M2500P.DAT	
CHINOOK-RAF	IAc	DASH DASH	Dash	SI:[3,11]U2S10PSHRT.DAT	
CHINOOK-RAF	IAw	see comment	Fire	SI:[3,11]P2FIREATT.DAT	see above
CHINOOK-RAF	Aw	MASTER CAUTION	Master Caution 1	SI:[3,11]WS16AIPMR.DAT	
CHINOOK-RAF	I	IFF CHANGE	Information	SI:[3,11]INFORAIMP.DAT	
CHINOOK-RAF	LH	LOW HEIGHT	Low height 2	SI:[3,11]M1M2500P.DAT	
SEAKING-RAE	IAw	see comment	Fire	SI:[3,11]P2FIREATT.DAT	A range of voice messages were provided :- PRIMARY SERVO PRESSURE; AUXILIARY SERVO PRESSURE; TRANSMISSION OIL PRESSURE; TRANSMISSION CHIP; GENERATOR FAIL; RECTIFIER FAIL; FIRE WARNING 1; FIRE WARNING 2; NO TRACK
SEAKING-RAE	Aw	MASTER CAUTION	Master Caution 1	SI:[3,11]WS16AIPMR.DAT	
SEAKING-RAE	LH	LOW HEIGHT	Low height 2	SI:[3,11]M1M2500P.DAT	
LYNX-RAE	IAw	see comment	Fire	SI:[3,11]P2FIREATT.DAT	A range of voice messages were provided :- ENGINE 1 OIL PRESSURE; ENGINE 2 OIL PRESSURE; HYDRAULICS 1; HYDRAULICS 2; FIRE WARNING 1; FIRE WARNING 2; ELECTRICS; MAIN GEAR BOX OIL PRESSURE; NO TRACK
LYNX-RAE	Aw	MASTER CAUTION	Master Caution 1	SI:[3,11]WS16AIPMR.DAT	
LYNX-RAE	LH	LOW HEIGHT	Low height 2	SI:[3,11]M1M2500P.DAT	
EH101	IAc(P1A)	ENGINE FAIL	Dash 3	SI:[3,11]U2S10PSHRT.DAT	
EH101	IAc(P1B)	ROTOR ROTOR	Wires 4	SI:[3,11]U2S5PSHRT.DAT	
EH101	IAw(P2A)	FIRE	Fire	SI:[3,11]P2FIREATT.DAT	
EH101	IAw(P2B)	WARNING	Fire	SI:[3,11]P2FIREATT.DAT	
EH101	Aw (P3A)	CAUTION	Master Caution 1	SI:[3,11]WS16AIPMR.DAT	
EH101	I (P4A)	150 FEET	Information 5	SI:[3,11]INFORAIMS.DAT	
EH101	LH (LH1A)	LOW HEIGHT	Low height 2	SI:[3,11]M1M2500P.DAT	

[1] = originally 'ELECTRICS'
[2] = derived from S09 SI:[3,11]WS14ABNVN.DAT
[3] = labelled 'THREAT' in confusion trial
[4] = labelled 'FUEL' in confusion trial
[5] = this is the first half of the original 'INFORMATION'

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Fig 1

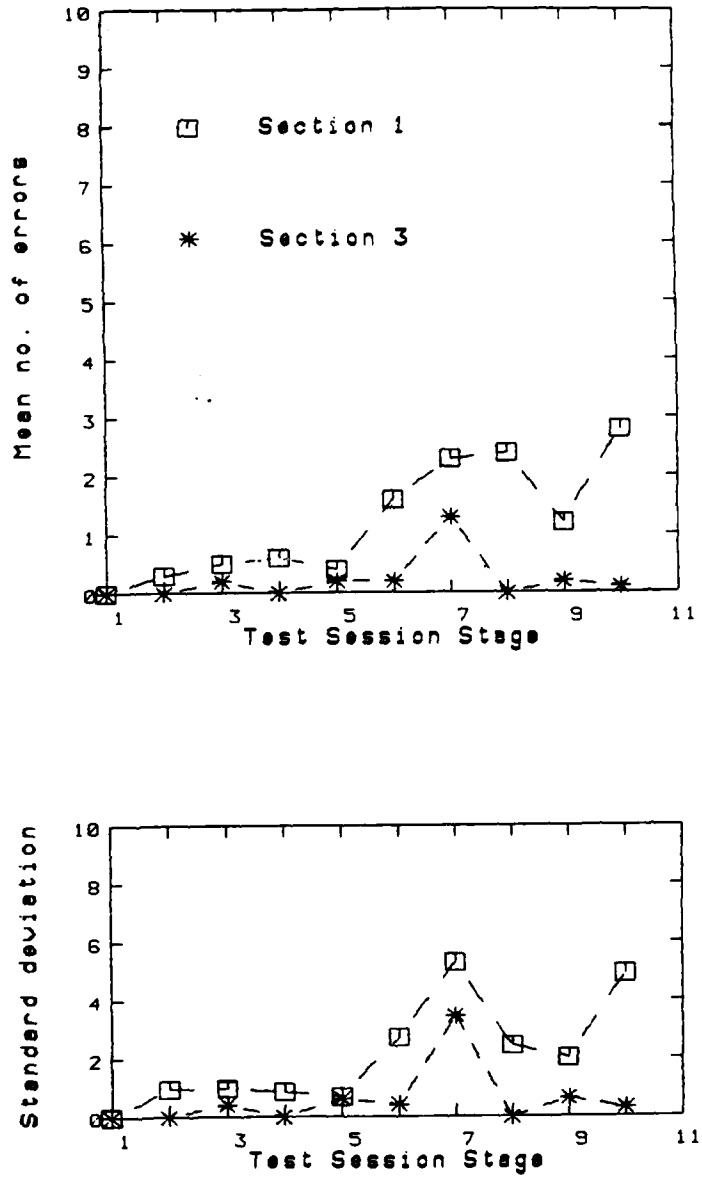

Fig 1 Mean response errors

Fig 2

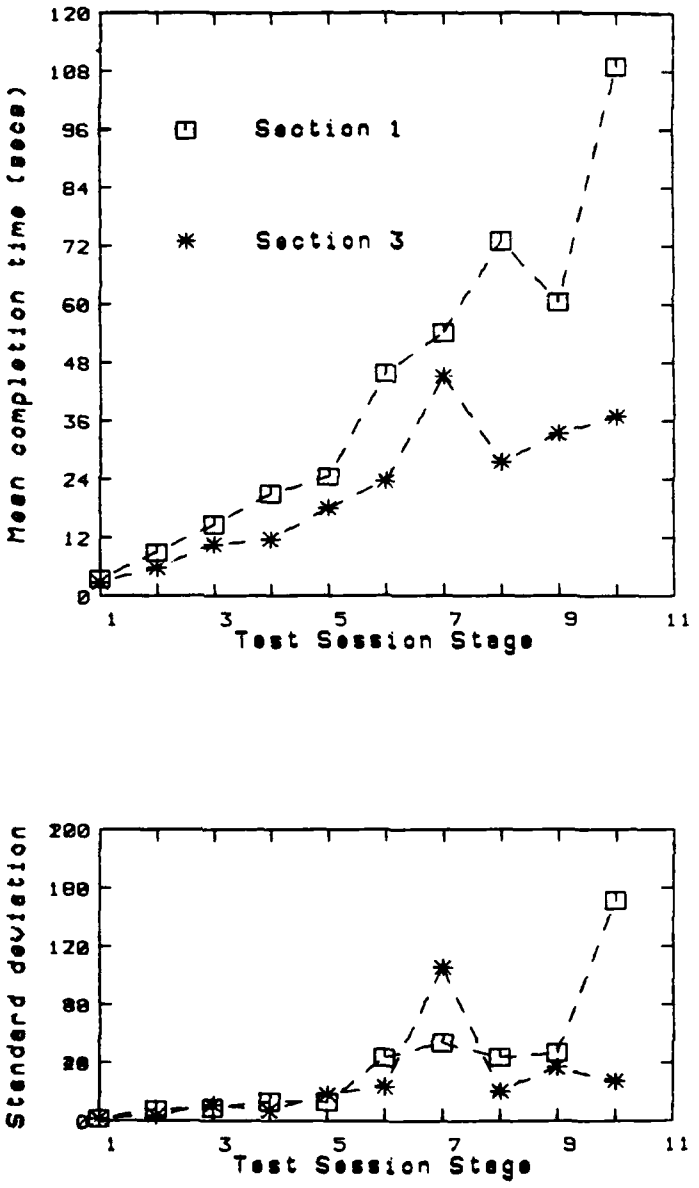

Fig 2 Mean completion times

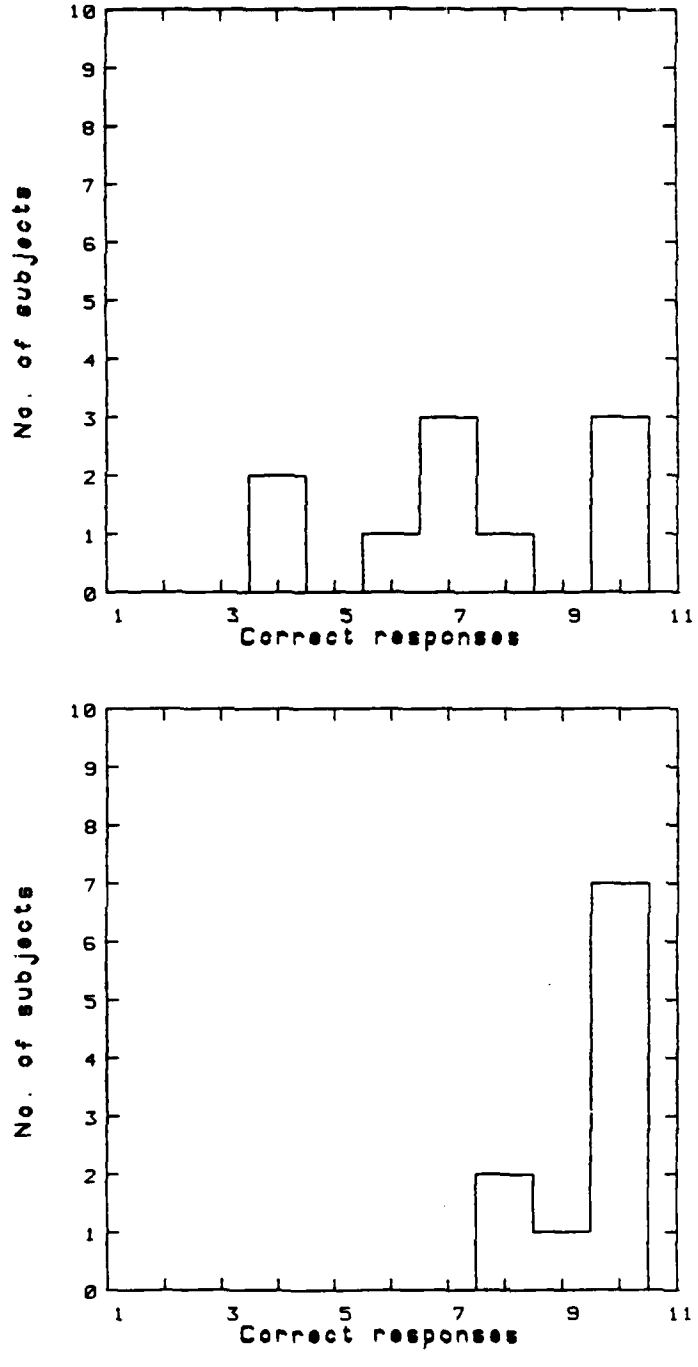

Fig 3 Test section scores

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNLIMITED

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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

17. Abstract

Following work by RAE (Farnborough), ISVR (Southampton University) and APU (MRC, Cambridge) a set of 40 high urgency warning signals were designed for RAE. The spectral content of the signals was designed to compensate for the acoustic characteristics of the aircraft, flight helmet and communication system.

An experiment was designed to select, from these 40 signals, the six which were perceived as conveying the greatest urgency, and then, to assess these in a set including four previously selected signals already in use in experimental auditory warning signals.

The data confirmed that those signals intended to be of the highest urgency were ranked correctly and that the relationships, in terms of perceived urgency, amongst the complete set of ten signals was as predicted.

A self-paced learning experiment was performed which showed that the signals were easily learnt and that there was no significant confusion amongst them.

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